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Utilization of Waste Low Density Polyethylene in High Strengths Concrete Pavement Blocks Production

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Abstract

The disposal of waste plastics is causing a great challenge in Ghana and the world as a whole as the usage of plastics is growing day by day and it takes centuries for waste plastics to decompose. Hence, there is the need to adopt effective methods to utilize these plastics. The main objective of this research was to investigate the feasibility of using waste low density polyethylene as partial replacement for sand in the production of concrete pavement blocks. In this study cement, sand, coarse aggregate, and ground plastic were used. The mix proportion was 1: 1.5: 3 (cement: sand: coarse aggregate). The plastic was used to replace the sand by volume at 0%, 10%, 20%, 30%, 40%, 50%, and 60%. It was observed that density, compressive strength, flexural strength, and splitting tensile strength decreased as the plastic content increased. However, the water absorption increased as the plastic content increased. Compressive strengths level ranging from 14.70N/mm^2 – 47.29N/mm^2 were achieved when water cement ratios of 0.30 – 0.45 were used. Although, the strengths of the pavement blocks decreased as the plastic content increased, compressive strengths of 20N/mm^2, 30N/mm^2, and 40N/mm^2 which are satisfactory for pedestrians walk ways, light traffic and heavy traffic situations respectively could be achieved if 10% - 50% plastic contents are used. It is concluded that the modified pavement blocks would contribute to the disposal of plastics in the world.

Keywords: plastic concrete pavement blocks, water cement ratio, compressive strength, curing age.

1. Introduction

Cement and aggregates, which are the most indispensable constituents used in concrete production are also vitae materials needed for the construction industry. This has led to a continuous and increasing demand of natural materials used for their production. Meanwhile, waste materials and by-products are being generated in vast quantities causing detrimental effect to the environment. It is therefore imperative to utilize these waste materials and by-products in construction applications. Recently, there have been successful applications of using local waste materials as a partial replacement for cement or aggregates in manufacturing concrete products in some parts of the world. Numerous researches on application of waste tyres as fine and coarse aggregates are available in the literature (Eldin and Senouci, 1993; Topcu, 1995; Toutanji, 1996; Khatib and Bayomy, 1999; Ling, 2011; Ohemeng and Yalley, 2013), which demonstrated the feasibility of using gargantuan amounts of waste tyre in concrete products.

Among the waste materials, plastic is one of the most common environmental issues in the contemporary world. Disposal of these plastics is considered to be a big challenge due to its non-biodegradable nature. Most of these plastics ended up in landfills and give the worst effect when they are burnt. In order to mitigate these hurdles, several researchers have made significant efforts to utilize waste plastics in concrete mixes. The density of plastic concrete is anticipated to be lowered than ordinary concrete due to the low specific gravity of plastics. Al-Manaseer and Dalal (1997) reported that the bulk density of plastic concrete decreased as the plastic content increased. The density was reduced by about 2.5%, 6%, and 13% when plastic content of 10%, 30%, and 50% respectively were used. Choi et al. (2005) investigated the effect of waste PET bottles aggregate on properties of concrete. The waste plastic could reduce the weight by 2 – 6% of normal weight concrete. Marzouk et al. (2007) studied the use of consumed plastic bottle as sand replacement and was noticed that the density lowered when the PET aggregate exceeded 50% by volume of sand. Suganthy et al. (2013) also mentioned a decreased in weight of concrete as the plastic content increased. It was noticed that there was linear relationship between decrease in weight and increase in plastic content.

Several authors have also reported on the strengths of plastic concrete. It is observed that increase in plastic aggregate content reduces the strengths of plastic concrete. Batayneh et al. (2007) mentioned that the incorporation of ground plastic in concrete had effect on its compressive strength. The compressive strength was reduced by about 23%, 35%, 50%, and 71% when fine aggregate of 5%, 10%, 15%, and 20% respectively were substituted with plastic. Naik et al. (1996) investigated the effect of post-consumer waste plastic in concrete as a soft filer. The test results showed lower compressive strength of the mix made with plastic than the reference mixture without plastic. Choi et al. (2005) also noticed a reduction in both compressive strength and splitting tensile strength. The compressive strength was lowered by 33% when compared to that of normal concrete. For the splitting tensile strength, increased in plastic content resulted in its reduction regardless of the water cement ratio used. Marzouk (2007) further reported a reduction of compressive strength in plastic concrete when the sand was replaced by plastic. Al-Manasser and Dalal (1997) again studied the effect of plastic on concrete mix. It was noticed that the splitting tensile strength decreased as the plastic content increased. Batayneh et al. (2007) also reported that the splitting tensile strength and the flexural strength of concrete mix slumped as the plastic content went up. The splitting tensile strength was lowered by about 56% when 20% of the aggregate content was replaced by plastic. The flexural strength was also decreased by about 40% when 15% of the aggregate was substituted with plastic.

The information presented shows that little attention has been given to the potential use of low density polyethylene (LDPE) as aggregate in concrete mixes, particularly for concrete pavement blocks. Therefore, the current research is aimed at investigating the possibility of utilizing LDPE as partial replacement for sand in the manufacturing of concrete pavement blocks (CPBs). The use of waste LDPE in CPBs will contribute to providing environmentally friendly solution for the plastic disposal problems in Ghana and the world as a whole.

2. Experimental Studies

2.1 Materials

The materials used to develop the plastic concrete pavement blocks (PCPBs) in this study consist of ordinary Portland cement (OPC), fine aggregate (sand), coarse aggregate (stones), ground plastic (GP) and water. Figure 1 shows samples of the cement, sand, stones, and ground plastic used.

Figure 1: Samples of the materials used to develop the PCPBs

2.1.1 Cement

Ordinary Portland cement (CEM I 42.5 N) produced by Ghana cement works (Ghacem) that conformed to EN 197-1 and labelled OPC was used. The mean particle size (μm) and specific gravity of the OPC were 4 and 3.14 respectively. Table 1 displays the chemical composition of the OPC.

Table 1: Chemical composition of ordinary Portland cement

Chemical composition	Content (%)
Silicon dioxide (SiO_2)	19.70
Aluminium oxide (Al_2O_3)	5.00
Ferric oxide (Fe_2O_3)	3.16
Calcium oxide (CaO)	63.03
Magnesium oxide (MgO)	1.75
Potassium oxide (K_2O)	0.16
Sodium oxide (Na_2O)	0.20
Sulphur oxide (SO_3)	2.80
Loss on ignition (LOI)	2.58

2.1.2 Sand, Coarse Aggregate, Ground Plastic and Water

Natural river sand from Jacobu in the Ashanti Region of Ghana was used for the PCPBs. The sand was dried in an opened place to remove the moisture. The sand conformed to zone II as per IS: 383 – 1970. The ground plastic used conformed to zone I as per IS: 383 – 1970. The coarse aggregate used in this study were 10 mm nominal size, and were tested as per IS: 383 – 1970. Table 2 shows the physical properties of the materials used whilst Figure 2 displays the graph of % passing of various materials used and sieve sizes. Potable water was used for the preparation and curing of the PCPBs specimens.

Table 2: Physical properties of sand, stones and ground plastic

Material	Specific gravity	Compacted bulk density (kg/m^3)	Fineness modulus	Moisture content (%)
Sand	2.60	1695.00	2.50	2.04
Stones	2.63	1723.00	1.97	1.39
Ground plastic	1.10	813.60	3.51	-

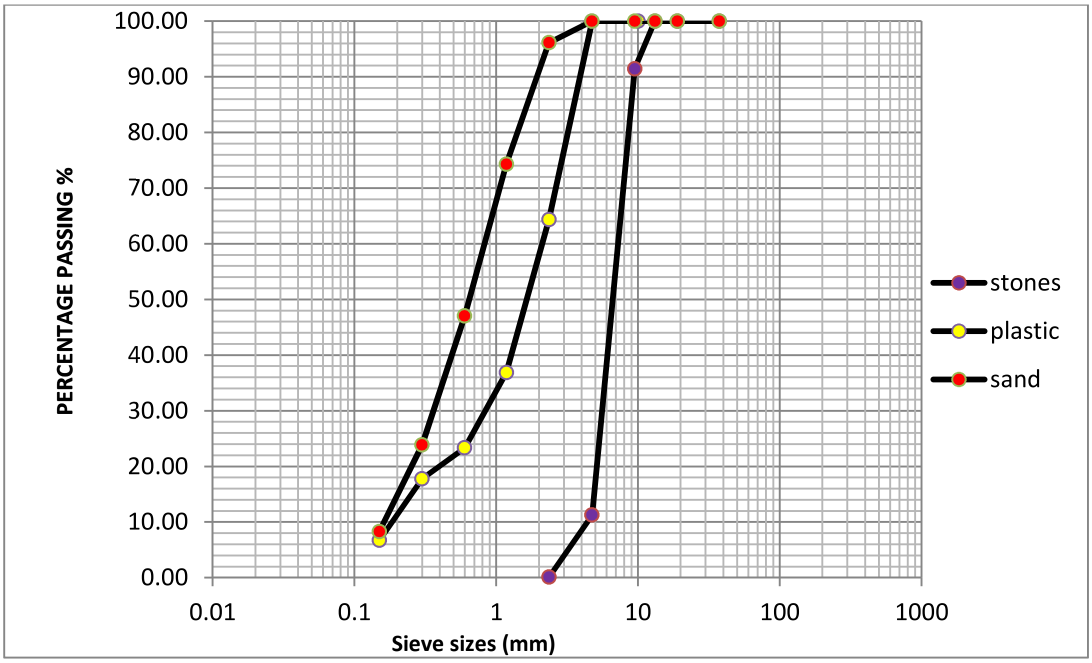

Figure 2: Graph of % passing of materials used and sieve sizes (mm)

2.1.3 Preparation of the Ground Plastic

Waste water sachets (type of low density polyethylene) were collected and cleaned. They were cut into pieces. The plastics were put on fire until they got melted. This caused the plastic's long chain polymer chains to break apart. The plastics in the liquid form were poured on roofing sheets and were allowed to solidify. With the aid of metallic mortar and pestle, the solidified plastics were ground into small particles. Figure 3 demonstrates the preparation process of the plastic.

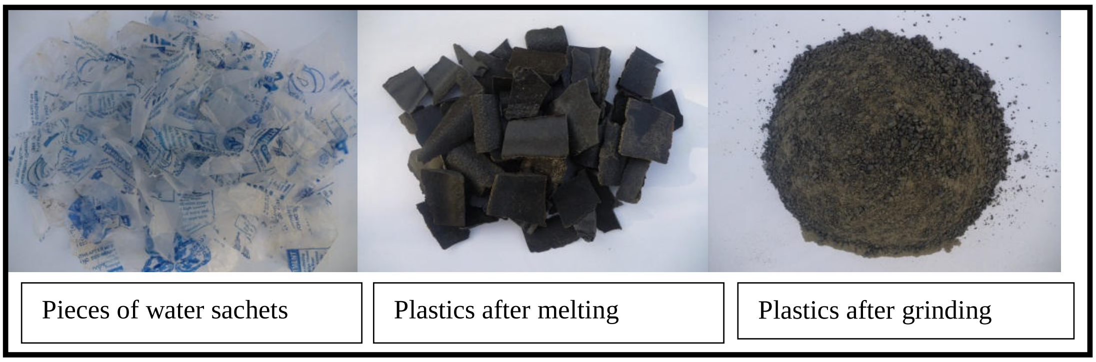

Figure 3: Preparation of the plastic

2.2 Methods

2.2.1 Proportion of the Mix

The mix proportion was 1: 1.5: 3 (cement: sand: coarse aggregate). The percentage weight of the ground plastic was 0%, 10%, 20%, 30%, 40%, 50%, and 60% by volume of sand. Different water cement ratios (0.30, 0.35, 0.40, and 0.45) were used for the experiment. The plain concrete was used as a control test and denoted as Aj, where j is the water cement ratio. The rest of the batches with ground plastic were denoted as Bi/j. Where B is the batch with certain % of plastic, i is the volume percentage of ground plastic and j is the W/C ratio. Table 3 exhibits the mix proportion of the aggregates used for the PCPBs.

Table 3: Mix proportion

Batch	Constituents of PCPBs (weight in kg)				
	Water	Cement	Coarse aggregate	Sand	Ground plastic (GP)
A0.30	0.882	2.940	8.840	4.420	0.000
A0.35	1.029	2.940	8.840	4.420	0.000
A0.40	1.176	2.940	8.840	4.420	0.000
A0.45	1.323	2.940	8.840	4.420	0.000
B10/0.30	0.882	2.940	8.840	3.978	0.212
B10/0.35	1.029	2.940	8.840	3.978	0.212
B10/0.40	1.176	2.940	8.840	3.978	0.212
B10/0.45	1.323	2.940	8.840	3.978	0.212
B20/0.30	0.882	2.940	8.840	3.536	0.424
B20/0.35	1.029	2.940	8.840	3.536	0.424
B20/0.40	1.176	2.940	8.840	3.536	0.424
B20/0.45	1.323	2.940	8.840	3.536	0.424
B30/0.30	0.882	2.940	8.840	3.094	0.636
B30/0.35	1.029	2.940	8.840	3.094	0.636
B30/0.40	1.176	2.940	8.840	3.094	0.636
B30/0.45	1.323	2.940	8.840	3.094	0.636
B40/0.30	0.882	2.940	8.840	2.652	0.848
B40/0.35	1.029	2.940	8.840	2.652	0.848
B40/0.40	1.176	2.940	8.840	2.652	0.848
B40/0.45	1.323	2.940	8.840	2.652	0.848
B50/0.30	0.882	2.940	8.840	2.210	1.060
B50/0.35	1.029	2.940	8.840	2.210	1.060
B50/0.40	1.176	2.940	8.840	2.210	1.060
B50/0.45	1.323	2.940	8.840	2.210	1.060
B60/0.30	0.882	2.940	8.840	1.768	1.272
B60/0.35	1.029	2.940	8.840	1.768	1.272
B60/0.40	1.176	2.940	8.840	1.768	1.272
B60/0.45	1.323	2.940	8.840	1.768	1.272

*Note: Density of sand = 1695.0 Kg/m^3 and density of GP = 813.6 Kg/m^3. Therefore, weight of GP for an equivalent volume of sand (conversion factor) = 813.6/1695.0
= 0.48

2.2.2 Preparation and Curing of PCPBs

Mixing of concrete and compaction of the blocks was done mechanically. The prepared PCPBs were packed on boards for 24 hours before curing started. They were cured under a shed. Water was poured on them twice in every day. This was done in order to prevent excessive evaporation of water from the PCPBs.

2.2.3 Testing of Specimens

The density of the PCPB was determined in accordance with BS 1881 – Part 114 (1983). The water absorption was tested in conformity with ASTM C 642 (2006). The compressive strength test was performed in accordance with BS 6717 – Part 1 (1986). To test the flexural strength, a centre line was marked at the top of the specimen, using a red marker perpendicular to its length. The PCPBs were tested under the centre line load while simply supported over supporting span of 150 mm (BSI, 2001). The flexural strength was then calculated from the formula; $\sigma = 3/2\ (LF / BD^2)$, where σ is the flexural strength (N/mm^2), L is the span length (mm), F is the maximum applied load (N), B is the average width of the specimen (mm), and D is the average thickness (mm). For the splitting tensile test, line loads were applied to the top and bottom of the PCPB using two steel bars. Plywood strips were inserted between the bars and the blocks to ensure even load distribution. Upon failure, the maximum applied load was recorded and the splitting tensile strength was calculated from the formula; $T = (0.868 \times K \times F) / (L \times D)$. Where T is the splitting tensile strength (N/mm^2), F is the load at failure (N), L is the length of the failure plane (mm), D is the thickness of the specimen at the failure plane (mm), and K is the correction factor for the thickness, calculated from the equation, $K = 1.3 – 30\ (0.18 – t/1000)^2$, t is the thickness of specimen.

3. Results and Discussion

3.1 Effect of W/C Ratio and Plastic Content on Strengths of PCPBs

Table 4 displays the results of the strengths of the PCPBs for various W/C ratios and plastic contents. It can be noticed that the compressive strength, splitting tensile strength, and flexural strength increase as the W/C ratio increases. The compressive strength increased from 38.12 N/mm^2 to 47.29 N/mm^2, 35.23 N/mm^2 to 43.58 N/mm^2, 31.14 N/mm^2 to 39.83 N/mm^2, 26.16 N/mm^2 to 31.95 N/mm^2, 22.52 N/mm^2 to 27.18 N/mm^2, 17.55 N/mm^2 to 21.89 N/mm^2, and 14.70 N/mm^2 to 18.81 N/mm^2 at 0%, 10%, 20%, 30%, 40%, 50%, and 60% plastic content respectively. The splitting tensile strength was moved from 3.98 N/mm^2 to 4.96 N/mm^2, 3.71 N/mm^2 to 4.52 N/mm^2, 3.32 N/mm^2 to 3.86 N/mm^2, 2.95 N/mm^2 to 3.54 N/mm^2, 2.64N/mm^2 to 2.99 N/mm^2, 2.16 N/mm^2 to 2.68 N/mm^2, and 1.81 N/mm^2 to 2.28 N/mm^2 at 0%, 10%, 20%, 30%, 40%, 50%, and 60% plastic content respectively. The flexural strength increased from 4.97 N/mm^2 to 5.84 N/mm^2, 4.70 N/mm^2 to 5.43 N/mm^2, 4.31 N/mm^2 to 4.98 N/mm^2, 3.84 N/mm^2 to 4.58 N/mm^2, 3.49 N/mm^2 to 3.91 N/mm^2, 2.89 N/mm^2 to 3.53 N/mm^2, and 2.58 N/mm^2 to 3.04 N/mm^2 at 0%, 10%, 20%, 30%, 40%, 50%, and 60% plastic content respectively. These indicate that the compressive strength, the splitting tensile strength, and the flexural strength were raised by about 24%, 22%, and 17%, respectively when the W/C ratio moved from 0.30 to 0.45 regardless of the plastic content used. A possible reason for the increase in strength may be due to the different quantities of water used for the preparation of the PCPBs. Concrete required certain amount of water for it to achieve its maximum strength during the hydration reaction of the cement paste. W/C ratio of 0.30 may be insufficient for the hydration reaction process. However, when the W/C ratio moved from 0.30 to 0.45, it may presuppose that the cement was getting adequate amount of water needed for the hydration process and consequently it may had a positive effect on the various strengths.

It can also be observed that the strengths of the PCPBs decreased as the plastic content increased (Table 4). The decrease pattern of the strengths is similar for the four different W/C ratios. The compressive strength reduced from 38.12 N/mm^2 to 14.70 N/mm^2, 41.66 N/mm^2 to 16.10 N/mm^2, 44.50 N/mm^2 to 17.30 N/mm^2, and 47.29 N/mm^2 to 18.81 N/mm^2 at 0.30, 0.35, 0.40, and 0.45 W/C ratios respectively. The splitting tensile strength decreased from 3.98N/mm^2 to 1.81N/mm^2, 4.31N/mm^2 to 2.05N/mm^2, 4.63N/mm^2 to 2.18N/mm^2, and 4.96N/mm^2 to 2.28N/mm^2 at 0.30, 0.35, 0.40, and 0.45 W/C ratios in order. The flexural strength lowered from 4.97 N/mm^2 to 2.58 N/mm^2, 5.28 N/mm^2 to 2.83 N/mm^2, 5.57 N/mm^2 to 2.98 N/mm^2, and 5.84 N/mm^2 to 3.04 N/mm^2 at 0.30, 0.35, 0.40, and 0.45 W/C ratios respectively. These suggest that the compressive strength, the splitting tensile strength, and the flexural strength were reduced by about 61%, 53%, and 46% respectively when 60% of the total sand was substituted with plastic irrespective of the W/C ratio used. The reason for the reduction in strengths could be attributed to the smooth surface of the plastic particles which might have reduced the adhesion between the boundaries of the plastic particles and the cement paste. The findings are supported by Batayneh et al. (2007) who experienced a reduction in compressive strength, flexural strength, and splitting tensile strength of plastic concrete as the plastic content increased.

Table 4: 28 day strengths tests results

Water cement ratio	Plastic content (%)	Compressive strength (N/mm^2)	Splitting tensile strength (N/mm^2)	Flexural strength (N/mm^2)
0.30	0	38.12	3.98	4.97
	10	35.23	3.71	4.70
	20	31.14	3.32	4.31
	30	26.16	2.95	3.84
	40	22.52	2.64	3.49
	50	17.55	2.16	2.89
	60	14.70	1.81	2.58
0.35	0	41.66	4.31	5.28
	10	37.14	3.91	4.89
	20	33.41	3.48	4.46
	30	27.86	3.21	4.17
	40	24.11	2.67	3.52
	50	19.85	2.48	3.32
	60	16.10	2.05	2.83
0.40	0	44.50	4.63	5.57
	10	41.44	4.31	5.28
	20	38.76	3.86	4.85
	30	29.30	3.32	4.31
	40	25.30	2.79	3.66
	50	20.83	2.50	3.33
	60	17.30	2.18	2.98
0.45	0	47.29	4.96	5.84
	10	43.58	4.52	5.43
	20	39.83	3.86	4.98
	30	31.95	3.54	4.58
	40	27.18	2.99	3.91
	50	21.89	2.68	3.53
	60	18.81	2.28	3.04

3.2 Impact of Curing Age on Strengths of PCPBs

The impact of curing age on the strengths of PCPBs is exhibited in Figures 4, 5, and 6. It is obvious that the compressive strength, the splitting tensile strength, and the flexural strength increase as the curing age increases regardless of the plastic content used. Critical examination of the figures shows that the compressive strength, the splitting tensile strength, and the flexural strength were increased by about 33%, 34%, and 32% respectively when the curing age moved from 7 days to 28 days irrespective of the plastic content used. The increase in strengths may be attributed to the hydration reaction of the cement paste which increases the strengths of concrete as curing age increases.

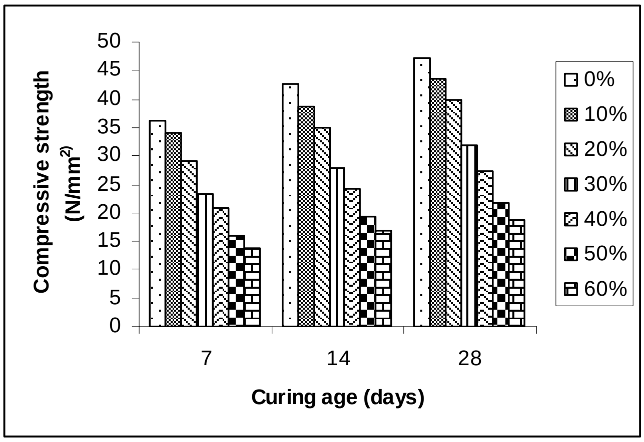

Figure 4: Compressive strength of different curing ages for W/C ratio of 0.45

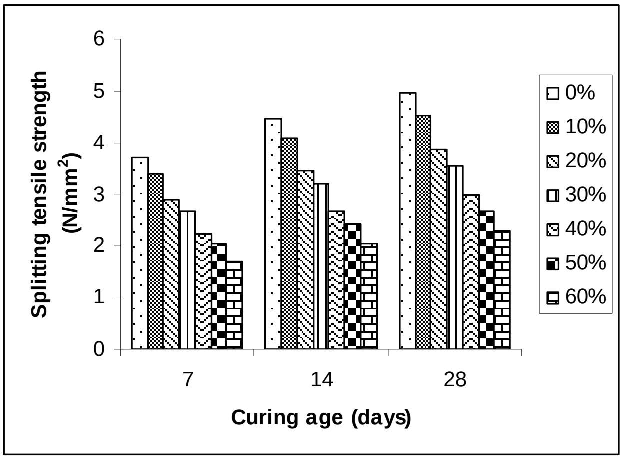

Figure 5: Splitting tensile strength of different curing ages for W/C ratio of 0.45

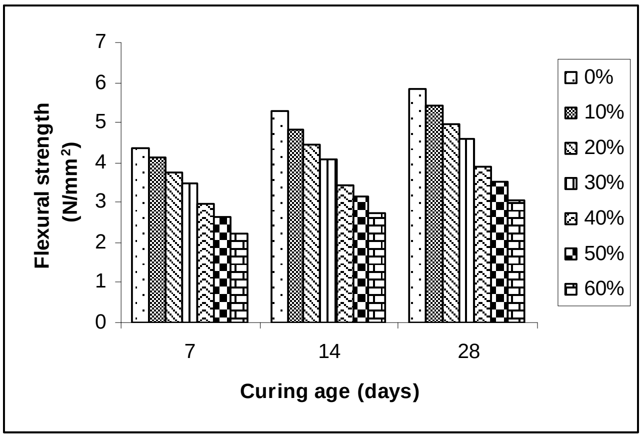

Figure 6: Flexural strength of different curing ages for W/C ratio of 0.45

3.3 Influence of Plastic Content on Density and Water Absorption

The influence of plastic content on density and water absorption is demonstrated in Table 5. It is observable that the density decreases as the plastic content increases. The density was lowered by about 10% when 60% of the total fine aggregate was replaced by plastic. The slump in density may be due to the low specific gravity of plastic (1.1) as compared to that of sand (2.6). The difference in the specific gravity exhibits that sand is heavier than plastic. Partially replacing volume of the sand by plastic would certainly reduce the masses of the PCPBs. Similarly, Al-Manaseer and Dalal (1997), Choi et al. (2005), Marzouk et al. (2007), and Suganthy et al. (2013) reported that density of plastic concrete decreased as the plastic content increased. It can also be realized that there was a linear correlation between plastic content and reduction in density (Figure 7). The coefficient of determination (R^2) = 0.9915 means that 99.15% of the variation in reduction in density of PCPBs can be explained by the plastic content.

It is also noticeable that the water absorption increases as the plastic content increases (Table 5). The water absorption moved from 1.44% to 1.76%, indicating a rise of about 22% when 60% of the sand was substituted with plastic. This upsurge may be influenced by the increase of voids in PCPBs as a result of the poor bond between the plastic particles and the cement paste in the mix. The relationship between plastic content and % increase in water absorption was found to be linear (Figure 8). The R^2 = 0.9966 indicates that 99.66% of the variation in water absorption can be explained by plastic content.

Table 5: Effect of plastic content on density and water absorption

Water cement ratio	Plastic content (%)	Density (Kg/m^3)	Reduction in density (%)	Water absorption (%)	% rise in water absorption
	0	2617.50	0.00	1.44	0.00
	10	2578.23	1.5	1.50	4.17
	20	2531.25	3.29	1.55	7.64
0.45	30	2507.92	4.19	1.59	10.42
	40	2467.08	5.75	1.64	13.89
	50	2426.25	7.31	1.70	18.06
	60	2367.50	9.55	1.76	22.22

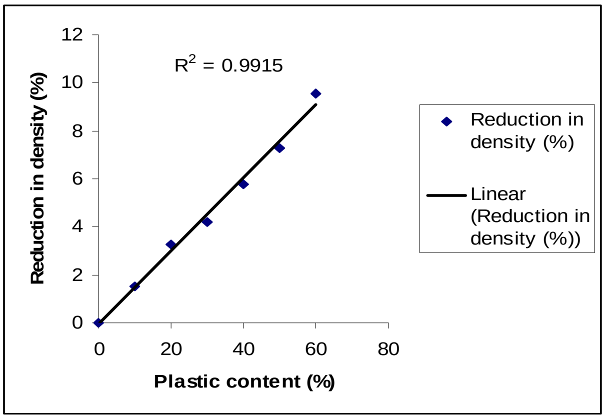

Figure 7: Relationship between plastic content and reduction in density (%)

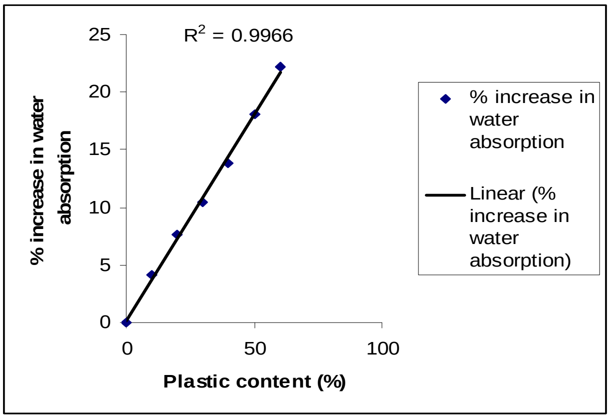

Figure 8: Relationship between plastic content and % increase in water absorption

3.4 Relationship between Density and Compressive Strength

Figure 9 displays the relationship between density and compressive strength of the PCPBs for water cement ratio of 0.45. It is apparent that there is linear correlation between the density and the compressive strength. The R^2 was found to be 0.9646. This suggests that 96.46% of the variation in compressive strength can be explained by the density of the PCPBs. It is also noticeable that compressive strength (Cs) = – 277.96 + 0.1244d. The – 277.96 is the constant value for determining the compressive strength. The 0.1244 means if density (d) is increased by one unit compressive strength will on average increase by 0.1244. A Pearson correlation was conducted to determine whether the correlation is statistically significant. It was realized that r = 0.982 and P < 0.001 (Table 6). Positive value of r indicates that as density increases, compressive strength increases. P < 0.001 shows that the correlation is statistically significant.

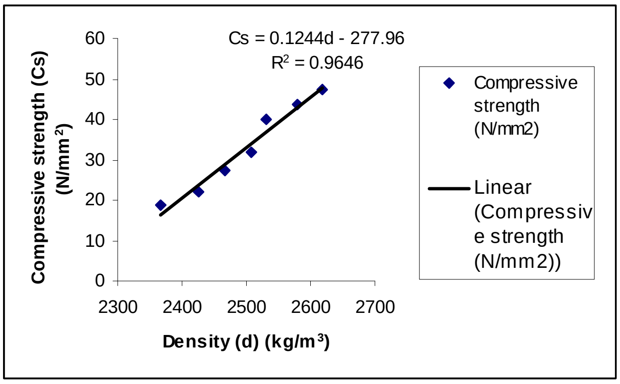

Figure 9: Relationship between density and compressive strength for W/C Ratio of 0.45

Table 6: Pearson correlation showing the statistical significance of the correlation between density and compressive strength

		Density	Compressive strength
Density	Pearson Correlation	1	.982**
	Sig. (2-tailed)		.000
	N	7	7
Compressive strength	Pearson Correlation	.982**	1
	Sig. (2-tailed)	.000	
	N	7	7

**. Correlation is significant at the 0.01 level (2-tailed).

4. Conclusions

The tests results of this study demonstrate that there is great potential for the utilization of waste low density polyethylene in concrete pavement block mixes, including 10%, 20%, 30%, 40%, and 50%. Based on these results, the following can be concluded:

Both physical and mechanical properties of plastic concrete pavement blocks were affected when plastic was used as a replacement for sand. Decrease in density, compressive strength, flexural strength, and splitting tensile strength was observed when part of the sand was substituted with plastic. The rate of reduction in density and strengths increased as the percentage of plastic increased. However, the water absorption of PCPBs increased as the plastic content increased.

Although, the strengths of PCPBs decreased as the plastic content increased, compressive strengths of $20N/mm^2$, $30N/mm^2$, and $40N/mm^2$ which are satisfactory for pedestrians walk ways, light traffic and heavy traffic situations respectively could be achieved if 10% - 50% plastic contents are used. The amount of waste plastic being accumulated in the world has created a big challenge for their disposal. Utilizing them in concrete pavement blocks will help to mitigate their effects.

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